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Quantitative method on miners emergency response capacity

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Abstract

A quantitative method is made to evaluate miners' emergency response capacity. Firstly, based on the safety engineering practices, an evaluation index system of individual emergency ability is established, and a hierarchical structure is set up, which includes security physiology, safety ability, individual psychology and sentiment in the top level. Secondly, Analytic Hierarchy Process is applied to determine each index's weight reasonably. Thirdly, fuzzy mathematical method is used to conduct the evaluation of single factor and the overall comprehensive evaluation respectively. Finally, for engineering practices, the method is used in a certain coal mine, and a set of appraise data is obtained, results shows that the quantitative method is help to select safety employers and reduce human-initiated mining accidents.

Keywords: safety engineering, miners, emergency response, quantitative method

1. Introduction

Improving miners' behaviours not only effectively prevent accidents, but also significantly increase safety performance [1]. So there will be of great realistic significance if we can evaluate miners' emergency response capacity truly and realistically which helps miners adapt post demands. Through analyzing human's safety behavior producing process of every link and each link's demanding emergency ability, and reviewing documents, this paper establishes an index system of individual emergency response ability based on safety behavior producing process, and it combines AHP with two hierarchical evaluation model to evaluate comprehensively , with this it obtains scientific and reasonable evaluation results.

As for the emergency response capability evaluation index system, many literatures are reviewed and analyzed. Liu Guojiang selects safety consciousness, knowledge and skills, emotional intelligence and physiological factors as the first grade indexes[2]. Liu Chao, Luo Yun and other people choose safety knowledge, safety capability, safety physiology and safety psychology[3].Zhang Jinggang, Tan Yunzhen and other people list professional quality, physical quality, safety consciousness and safety education[4].Wang Shuangying use safety technology quality, cultural quality,safety psychological(quality, cultural awareness and safety training[5]. Chen Liyan assorts cultural quality, professional ethics, situation cognition and decision-making, and work abilityand and so on[6]. From above it shows the division of index systems' first grade index has no theoretical basis and standards, and it mainly conducts with perceptual experiences. This paper selects security physiology, safety ability, individual psychology

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and sentiment as first grade index. Compared with other index system, this system is more improving, and the classification is more standard.

2. Construction of Fuzzy Comprehensive Evaluation Model

Fuzzy Comprehensive Evaluation Method is a comprehensive evaluation method based on fuzzy mathematics principle [7, 8], this method uses fuzzy mathematics to make a whole evaluation about a subject is restricted by multiple factors. It has the features of strong in result and clear in result. It can well solve problems that are vague and difficult to quantify, and it is suitable for the solutions all kinds of uncertain problems.

2.1. Establishment of Evaluation Index System

The establishment of evaluation index system is an important part of the whole safety assessment work; it determines the scientific and objective degree of evaluation results. On the basis of investigation of large numbers of miners' emergency response ability and with reference to relevant materials document to analyze accident cases, the writer picks 4 first grade assessment indexes--safety physiology, safety ability, individual psychology and sentiment，and also select 14 second grade indexes. The constructed index system is shown below in figure 1.

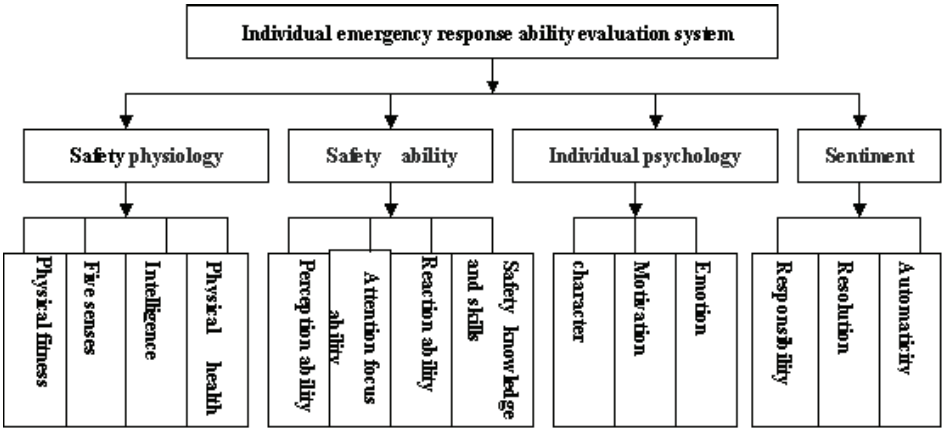

Figure 1 Individual emergency response ability evaluation index system

2.2. Establishment of Factor Set and Evaluation Set

Factor set is a collection of each factor affecting evaluation object. When there are many factors influencing assessment object, it will lead to the disappear of some small weight factors if using first grade fuzzy assessment model, at this time it's more reasonable to use secondary fuzzy comprehensive evaluation. Suppose first grade factor set affecting evaluation object as: $U = \{U_1, U_2,\ldots, U_n\}$. Suppose secondary single factor set affecting evaluation object as: $U_1 = \{u_{11}, u_{12}, \ldots, u_{1n1}\}$, $U_2 = \{u_{21}, u_{22}, \ldots, u_{2n2}\}, \ldots, U_n = \{u_{u1}, u_{n2}, \ldots, u_{nnn}\}$.

Comment set is a collection of m evaluation grades regarded as evaluation standard, denoted by $V = \{V_1, V_2, \ldots, V_m\}$. Comment grade must be chose properly, considering that three grades comment is too rough, and seven grades comment is too detailed, this paper selects five grades comment set as: $V = \{V_1, V_2, V_3, V_4, V_5\}$ = {very good, good, moderate, bad, very poor}..

Judgment matrix R is obtained by the relationship between U and V, Denoted by $R=(r_{ij})_{n\times m}$ (j=1,2，…, m）. Type: r_{ij} refers to the extent of u_i in U belonging to V, valuing the grade which factors belong to as 1, otherwise value it as 0. If it's uncertain to determine which grade a factor belongs to, any number between 0 and 1 can quantitatively describe fuzzy object by means of experience.、

2.3. Establishment of Weight Set and Determination of Index Weight

Weight set is a set of different weights a_i giver by each factor U_i 's importance degree in U. denoted by A = $\{a_1, a_2, \ldots a_n\}$, including $\sum_{i=1}^{n} ai = 1$, $0 \le a_i \le 1$.

The determination of weight coefficient ai is one of the most key steps in comprehensive evaluation; this will directly affect comprehensive evaluation results。There are many methods to of determine weight, such as qualitative experience of Delphi method、composition analysis method of the statistics of quantitative data and Analytical Hierarchy Process (AHP) combining qualitative method and quantitative method and so on. This article mainly use AHP to determine each evaluation index's weight, the calculating processes are as follows.

1) Principle of hierarchical analysis

AHP is a combination of qualitative method and quantitative method [9], it uses number form to express individual subjective judgment.This method tries to reduce personal subjective judgment, and make evaluation results more credible. The basic thoughts are: make a comparison of every two elements of each level, first establish judgment matrix according to 1~ 9 scale theory in Table 1, and calculate the maximum eigenvalue and its corresponding eigenvector of judgment matrix, then obtain significant sequence of each level factors to upper level factors, and finally establish the weight vector.

Table 1 judgment matrix's important scale and implication

Scale	Implication
1	Said the two compared elements, have the same importance
3	Said comparing the two elements, a factor is a little important than the other one
5	Said comparing the two elements, a factor is obviously important than the other one
7	Said comparing the two elements, a factor is strongly important than the other one
9	Said comparing the two elements, a factor is extremely important than the other one
2.4.6.8	Said the median of two adjacent judgment above

2) Construction of judgment matrix according to the 1 ~ 9 scale theory

According to 1 ~ 9 scale theory, judgment matrix can be constructed out. As comparing two factors through this principle, relative importance can be divided into nine grades. When judgment objects are different in quality, namely equally important, a little important, obviously important, strongly important, extremely important, scale values are 1、3、5、7、9 in sequence; When in between, scale values are 2、4、6、8. Judgment matrix A of each level can be got on basis of the principle and factor sets, notes for: A= （aij）, aij＞0 included.

3) Calculation of factors weights on basis of root method

This paper applies root method to obtain the maximum eigenvalue and eigenvector W=（W_1,W_2,…,W_n）, the specific calculation process is as follows:

(1) Calculate the product Mi of matrix's every element in each line: $M_i = \prod_{j=1}^{n} a_{ij}$

(2) Calculate M_i's n-th root W_i': $W_i' = \sqrt[n]{Mi}$

(3) Normalize W_i' to get the obtained eigenvector W_i: $W_i = W_i' / \sum_{i=1}^{n} Wi'$.And W=（$W_1$,$W_2$, …,$W_n$）^{T}, namely the obtained eigenvector approximation, that's also each factor' s weight.

(4) Calculate of matrix's maximum eigenvalue λ max: $\lambda \max = \sum_{i=1}^{n} \frac{(AW)i}{nWi}$

(5) Consistency check: calculate the check coefficient $CR = \frac{CI}{RI}$, including $CI = \frac{(\lambda \max - n)}{n-1}$

Type, CI: consistency index; CR: random consistency ratio; RI: mean random consistency index, For 1 ~ 9 order matrix, mean random consistency index RI can be found in Table 3. When CR = 0, A has a complete consistency; When CR < 0.1, A has A satisfactory consistency; When CR > 0.1, A has a non-satisfactory consistency, at this time weights should be adjusted by experts.

Table 2 mean random consistency index,

Order n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.96	1.12	1.24	1.32	1.41	1.45

2.4. Construction of fuzzy comprehensive evaluation matrix

(1) Construction of one-level fuzzy comprehensive assessment

One-level comprehensive evaluation matrix Bi: Bi=Wi·Ri=（b1， b2， b3， b4）.Based on maximum membership degree law, the corresponding grade of the maximum in Bi is its safety degree.

(2) Construction of the secondary fuzzy comprehensive evaluation matrix

the results Bi of one-level evaluation makes up of R, R uses as single-factor assessment set, then draw the secondary comprehensive evaluation: B = W·R.

2.5. Calculation of fuzzy evaluation total score

Dealing with B, it transfers each grade into score system, for example, score every grade in centesimal grade(see Table 3) ,then can obtain the system's total score : f=c1b1+c2b2+c3b3+c4b4+c5b5, finally gets its security level referring to Table 4.

Table 3 grades in centesimal grade

Score c	95	80	65	45	30
Safety Grade	very good	good	moderate	bad	very bad

Table 4 list of safety grade

Evaluation total score f	＞90	90～80	79～60	59～40	＞40
Safety Grade	very good	good	moderate	bad	very bad

3. Case Application

Making a coal mine of a certain area as an example, the writer tries to show the application of fuzzy comprehensive evaluation model in the evaluation of miners' emergency response capacity. The judgment matrix and weights of safety physiology can be seen in Table 5.

Table 5 multiple comparison judgment matrix and determination of weight

Factor U	physical fitness	Five senses	intelligence	physical health status	M1	W1'	W1
physical fitness	1	3	4	2	24	2.213	0.467
Five senses	1/3	1	2	1/2	1/3	0.760	0.160
intelligence	1/4	1/2	1	1/3	1/24	0.452	0.095
physical health status	1/2	2	3	1	3	1.316	0.278

Based on the values of judgment matrix A in Table 5, eigenvector W1 can be got through using formulas, meanwhile calculating maximum eigenvalue λ max=4.034, and get a CR=0.012＜0.1, therefore, the judgment matrix can be

Accepted, simultaneously, the weights of other factors can also be obtained, so evaluation factors' weights of personal emergency capability are shown below:

Weights of safety physiology factors: $W_1=(0.467 \quad 0.160 \quad 0.095 \quad 0.278)$；

Weights of safety ability factors: $W_2=(0.087 \quad 0.296 \quad 0.140 \quad 0.477)$：

Weights of individual psychology and sentiment factors:

$W_3=(0.230 \quad 0.648 \quad 0.122)$;

Weights of sentiment factors: $W_4=(0.625 \quad 0.136 \quad 0.239)$;

Weights of individual emergency capacity factors:

$W=(0.306 \quad 0.491 \quad 0.125 \quad 0.078)$;

According to the formulas, the fuzzy comprehensive evaluation matrix B1 of safety physiological factor is as follows;

$$B_1=W_1\cdot R_1=(0.467 \quad 0.160 \quad 0.095 \quad 0.278)\begin{pmatrix}1&0&0&0&0\\0&1&0&0&0\\0&0&1&0&0\\0&1&0&0&0\end{pmatrix}$$

$$=(0.467 \quad 0.438 \quad 0.095 \quad 0 \quad 0)$$

Similarly, $B_2=(0.564 \quad 0.436 \quad 0 \quad 0 \quad 0)$; $B_3=(0.625 \quad 0.239 \quad 0.136 \quad 0 \quad 0)$;

$B_4=(0.648 \quad 0.23 \quad 0.122 \quad 0 \quad 0)$;

This can get secondary fuzzy matrix:

$$R=\begin{pmatrix}B1\\B2\\B3\\B4\end{pmatrix}=\begin{pmatrix}0.476&0.438&0.095&0&0\\0.564&0.436&0&0&0\\0.625&0.239&0.136&0&0\\0.648&0.23&0.122&0&0\end{pmatrix}$$

So the second fuzzy comprehensive evaluation set is as follows:

$$B=W\cdot R=(0.306 \quad 0.491 \quad 0.125 \quad 0.078)\begin{pmatrix}0.476&0.438&0.095&0&0\\0.564&0.436&0&0&0\\0.625&0.239&0.136&0&0\\0.648&0.23&0.122&0&0\end{pmatrix}$$

$$=(0.542 \quad 0.37 \quad 0.077 \quad 0 \quad 0);$$

Conduct the normalization of B , and get $B'=(0.548 \quad 0.374 \quad 0.078 \quad 0 \quad 0)$;

The total score of Miners' personal emergency response ability is:

$f=c1b1+c2b2+c3b3+c4b4+c5b5=95\times0.548+85\times0.37+65\times0.077+45\times0+35\times0=88.9$

From the final comprehensive evaluation score f =88.9 points, it can be known that the comprehensive evaluation grade of miners' emergency ability is good.

4. Conclusion

(1) Fuzzy comprehensive evaluation model fully considers the uncertainty and imprecision of evaluation factors, and evaluation results are consistent with the example presented on miners' personal emergency ability. This indicates that method used has certain feasibility and reference value.

(2) An important precondition to evaluate miners' emergency capacity though fuzzy comprehensive model is to establish a scientific and reasonable evaluation index system, but there's no unified divided standard on this currently, so standardization work of emergency capability should be strengthen.

(3) Though fuzzy comprehensive evaluation method, it can be known that the final evaluation score of the miners' emergency capacity is 88.9 points, belong to the grade " good " ,this demonstrates the overall safety condition of miners in this coal mine is much ideal, but still can't treat it lightly.

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